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Decision support for sustainable household waste processing: a comparative evaluation of ahp and fuzzy ahp

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ABSTRACT

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Urban household waste management in developing countries faces increasing complexity due to population growth, land constraints, and socio-environmental considerations. This study proposes a comparative evaluation of the Analytic Hierarchy Process (AHP) and Fuzzy AHP to support decision-making in selecting sustainable household waste treatment alternatives in Umbulharjo Sub-district, Yogyakarta City, Indonesia. Five sustainability criteria and five alternative treatment methods were identified through expert consultation and literature review. Primary data were collected from 20 household respondents using structured questionnaires. The AHP method applied a crisp pairwise comparison scale, while Fuzzy AHP incorporated linguistic assessments converted into Triangular Fuzzy Numbers to better handle uncertainty and subjectivity. The results demonstrate that while AHP prioritizes the burning method due to perceived simplicity and feasibility, Fuzzy AHP reveals a stronger preference for "Sorting, Hoarding, and Selling," reflecting the community's implicit environmental and economic concerns. The divergence in outcomes highlights the limitations of deterministic assessments in complex socio-technical systems and underscores the added value of fuzzy logic in capturing nuanced stakeholder preferences. By integrating quantitative and qualitative criteria within a hierarchical decision framework, this study contributes to the development of more context-sensitive and adaptive decision-support tools. The findings offer practical guidance for municipal authorities and urban planners seeking to align waste management strategies with cleaner production principles. The proposed methodological framework enhances transparency, inclusiveness, and responsiveness in sustainability assessments, supporting the transition toward more resilient and community-driven urban waste systems.

1. Introduction

The amount of solid garbage generated by households has increased dramatically in emerging nations due to rapid urbanization and population development. As one of Indonesia's cultural and metropolitan centers, Yogyakarta City is under growing pressure to create sustainable household waste management (HWM) systems that support social and economic goals while also minimizing environmental impact. Effective waste treatment is hampered in densely populated Sub-districts like Umbulharjo by a lack of available land, a variety of waste types, and low levels of community involvement in garbage segregation. Sustainable household waste management plays a vital role in achieving broader sustainability goals, especially in urban areas. Various technologies such as composting, anaerobic digestion, incineration, and community-based waste banks have been proposed to address these issues. However, selecting the most suitable treatment method remains complex due to the need to simultaneously evaluate multiple criteria, including economic feasibility, environmental impact, social acceptance [1].

Analytic Hierarchy Process (AHP) and fuzzy AHP approaches were used in this study to identify the most environmentally friendly household waste management plan in Umbulharjo Sub-district, Yogyakarta. Creating a hierarchical framework with objectives, standards, and options was the first step. Interviews with experts and literature study resulted in the identification of five criteria and five options. AHP used a scale of 1 to 9 to generate a pairwise comparison matrix. To ensure the evaluation was reliable, the Consistency Ratio (CR) was calculated [2], [3].

Meanwhile, Fuzzy AHP extends this approach by allowing linguistic terms for judgments, which are then translated into triangular Fuzzy numbers. This hybrid method is better at capturing vagueness and subjectivity in experts opinions [4]. Primary data was collected from 20 household respondents using a structured questionnaire. Data analysis was done using Excel, the final decision matrix in AHP and Fuzzy AHP was used to rank the alternatives. Offers a structured approach using pairwise comparisons to rank alternatives based on hierarchical decision models [5].

However, AHP assumes precise numerical judgments, which may not fully capture the ambiguity and imprecision inherent in human assessments [6]. To enhance the realism and robustness of AHP, the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) integrates Fuzzy set theory into the AHP framework [7]. This allows decision makers to express their preferences using linguistic terms, which are then converted into Triangular Fuzzy Numbers (TFNs). This hybrid approach has demonstrated strong performance in various sustainability domains such as renewable energy [26], logistics and facility location [27], and campus waste planning [8]. However, comparative applications of AHP and Fuzzy AHP for prioritizing household waste treatment options at the Sub-district level in Indonesia remain limited in current academic literature.

This study seeks to fill this gap by conducting a comparative analysis of AHP and Fuzzy AHP to evaluate sustainable household waste treatment alternatives in Umbulharjo Sub-district, Yogyakarta City, Indonesia. The study aims to build a decision-making framework that reflects local stakeholder preferences while promoting sustainability principles. The specific objectives of this research are: (1) to identify and structure relevant sustainability criteria for household waste treatment in the urban Indonesian context; (2) to apply AHP and Fuzzy AHP methods to evaluate and prioritize feasible waste treatment alternatives; and (3) to compare the results, performance, and sensitivity of both methods in handling uncertainty and providing decision support. The central hypothesis is that integrating Fuzzy logic into AHP will improve the flexibility, accuracy, and contextual sensitivity of the decision-making process, particularly in complex and uncertain environments. By adopting this dual methodological approach, the study contributes theoretically to the refinement of Fuzzy based MCDM methods and practically to the design of sustainable, community focused waste management strategies in urban Southeast Asia.

2. Method

In order to eliminate the ambiguity of human judgment, this study used one of the techniques in Multi Criteria Decision Making (MCDM), namely Analytic Hierarchy Process (AHP) and Fuzzy AHP [7], [8]. To establish a sustainable home waste management strategy in Umbulharjo Sub-district. This method facilitates decision-making by prioritizing different possibilities according to a set of predetermined criteria. However, AHP offers a strong foundation for judgment. Given that many sustainability assessment criteria are qualitative and open to interpretation, fuzzy set theory provides a more effective way to capture stakeholder preferences and expert insights [2], [9].

This theory states that judgments can be stated in language and then transformed into fuzzy numbers for analysis in a computer [10]. AHP has limits when it comes to handling the ambiguity and uncertainty that frequently occur in real-world scenarios. To rule out the likelihood of such events, fuzzy set theory is integrated with the study approach. Combining fuzzy set theory and AHP leads to the management of uncertainty. This hybrid approach preserves the AHP's clarity while improving its capacity to manage the ambiguity and uncertainty present in human judgment [4].

The suggested method for evaluating waste management makes use of fuzzy AHP. This technique allows decision makers to utilize words to express comparison assessments, which are subsequently transformed into triangular fuzzy numbers for analysis [1]. This approach eliminates confusion in the decision-making process while providing a more realistic representation of the issue at hand. The comparison between the AHP and fuzzy AHP methods in this study indicates that, even if both methods produce good alternative results, there is a significant difference in their prioritization [5]. Because it uses a precise numerical scale, the AHP method consistently yields very high values, complicating interpretation of the ambiguity and uncertainty arising from respondents' questionnaires [11].

In contrast, Fuzzy AHP accounts for uncertainty by using Triangular Fuzzy Number (TFN) calculations that incorporate pessimism, probability, and optimism. This enables a more realistic representation of qualitative analysis [12]. As an example, the alternative "Sorting, Hoarding and Selling" has a higher threshold for fuzzy AHP than for AHP, which indicates that respondents' perceptions are generally more favorable to environmental and economic factors, even if they are not explicitly stated in numerical form.

Accordingly, fuzzy AHP is more sensitive to local contexts and more accurate in determining stakeholder preferences, making it a more flexible method for developing complex strategic plans that are not as straightforward as household waste [13].

In order to close this gap, this study compares AHP and fuzzy AHP in order to assess which household waste management approach in Umbulharjo Sub-district, Yogyakarta City, Indonesia, is the most sustainable. The goal of this study is to develop a framework for decision-making that emphasizes sustainability principles while taking into account the interests of regional stakeholders. Three scenarios are used in this study to compare various TFNs. Scenario 1 made use of the AHP scale. TFN is used in Scenario 2 by adhering to the technique.

The suggested method was used in the scenario. To prioritize criteria and alternatives for creating a sustainable household waste management strategy, the scenario outcomes were examined. A hierarchical framework comprising objectives, criteria, and alternatives is compiled to apply fuzzy AHP systematically to sustainable household waste management in Fig. 1. The primary goal is to assess methods for managing household garbage. Criteria are the next level of the hierarchy, while options are the final level. Pairwise comparisons between criteria and alternatives are performed using fuzzy pairwise comparisons, which are further transformed into triangular fuzzy numbers (TFN) [12] in Fig. 2.

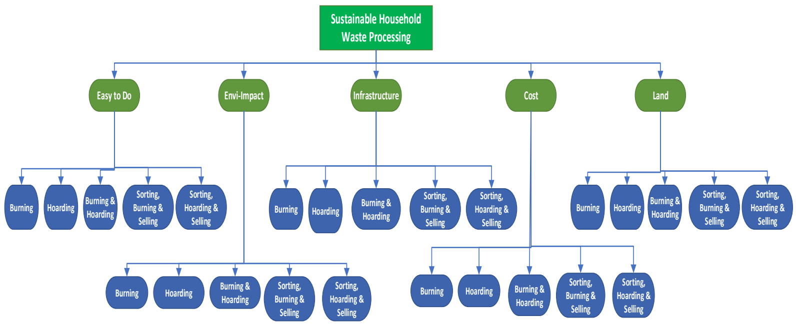

Fig. 1. Hierarchy Framework [2]

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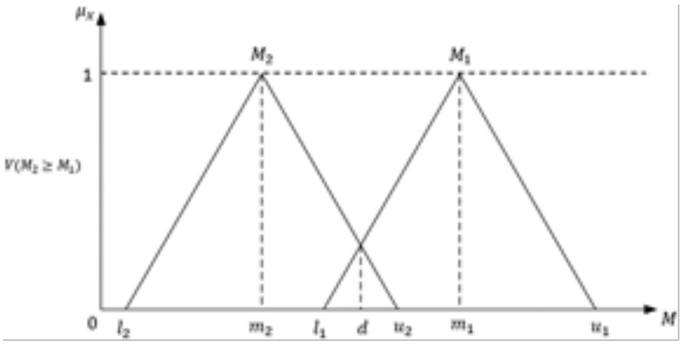

Fig. 2. Triangular Fuzzy Number (TFN) [14]

Table 1. Linguistic Variables Corresponding to the 1-9 Scale and Fuzzy Triangular Scale

Linguistic variables	AHP	Fuzzy AHP	
	Scenario 1	Scenario 2	Scenario 3
		[5]	[15]
Equally important	1	(1,1,1)	(1,1,1)
Intermediate value	2	(1/2,1,3/2)	(1,2,3)
Moderately	3	(1,3/2,2)	(2,3,4)
important			
Intermediate value	4	(3/2,2,5/2)	(3,4,5)
Important	5	(2,5/2,3)	(4,5,6)
Intermediate value	6	(5/2,3,7/2)	(5,6,7)
Very important	7	(3,7/2,4)	(6,7,8)
Intermediate value	8	(7/2,4,9/2)	(7,8,9)
Extremely important	9	(4,9/2,9/2)	(9,9,9)

3. Results and Discussion

This study analysis examines three distinct decision-making scenarios aimed at evaluating sustainable household waste management alternatives. Scenario 1 employs the traditional Analytic Hierarchy Process (AHP), a structured technique for organizing and analyzing complex decisions using pairwise comparisons and expert judgments. In contrast, Scenarios 2 and 3 utilize the fuzzy Analytic Hierarchy Process (fuzzy AHP), an extension of the conventional AHP method that incorporates elements of fuzzy logic to better handle the uncertainty and subjectivity inherent in human assessments. Each fuzzy scenario applies different types of fuzzy number representations (e.g., triangular or trapezoidal fuzzy numbers), allowing for a more nuanced understanding of stakeholder preferences and judgments. By applying multiple scenarios, this comparative study provides valuable insights into how different methodological approaches especially the treatment of uncertainty can influence the prioritization of sustainability aspects in household waste management [16]. The variation in results among the scenarios underscores the importance of selecting an appropriate decision-support tool that aligns with the complexity of real-world issues, particularly in community-level environmental management.

From this study, the traditional AHP method in Scenario 1 assigns the highest priority weight to the burning method, which is likely due to the method's perceived simplicity, low immediate cost, and ease of implementation, particularly in areas with limited infrastructure or formal waste management systems. In contrast, the results derived from the fuzzy AHP analysis in Scenarios 2 and 3 provide a more refined picture of the community's preferences by factoring in uncertainty and linguistic judgments. The global priority weights for each waste management alternative in Umbulharjo Sub-district are as follows: Burning: 0.449; Sorting, Hoarding, and Selling: 0.250; Hoarding: 0.246; Burning and Hoarding (combined method): 0.055 as show in figures below.

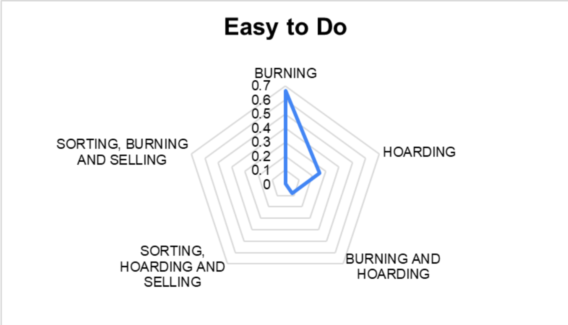

Fig. 3. The Alternative Weight for Easy to DO

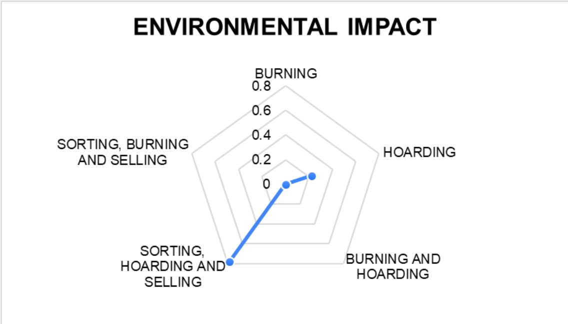

Fig. 4. The Alternative Weight for Envi Impact

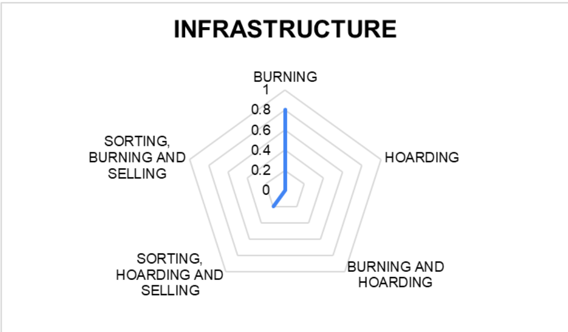

Fig. 5. The Alternative Weight for Infrastructure

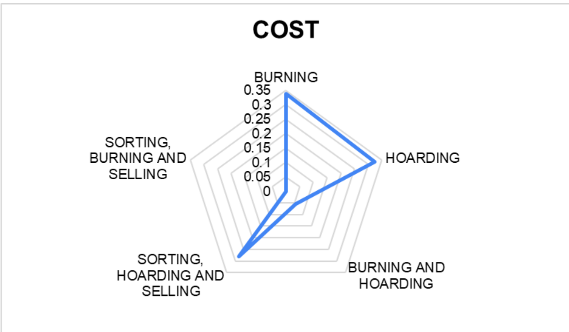

Fig. 6. The Alternative Weight for Cost

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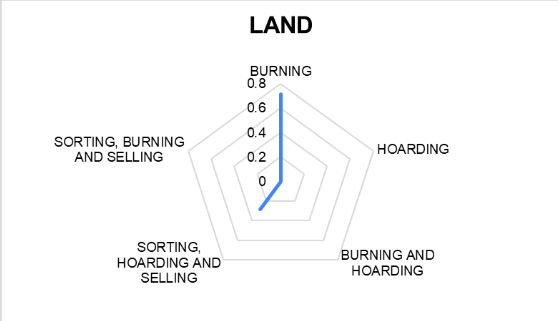

Fig. 7. The Alternative Weight for Land

The findings reveal that burning stands out as the dominant alternative with a global weight of approximately 0.45, indicating that incineration is still perceived as the most practical option under the given decision criteria. This aligns with previous studies in developing countries, where open burning remains a common practice due to its low cost and immediate feasibility [17], [18] in Fig. 6. However, this reliance on burning also reflects a limited awareness of its environmental and health risks, particularly the emission of toxic pollutants and greenhouse gases in Fig. 4. Meanwhile, hoarding and the combined alternative burning and hoarding obtained weights of 0.24–0.25, suggesting that communities tend to rely on temporary storage, often as a transitional practice before final disposal. Similar findings have been reported in rural areas of Southeast Asia, where waste accumulation near households is considered a coping strategy in the absence of reliable collection systems [19], [20].

In contrast, sorting, hoarding, and selling was rated very low (0.055) and sorting, burning, and selling was negligible (0.0). This result demonstrates that waste separation and resale for recycling are not widely adopted practices. Such tendencies are consistent with studies in low- and middle-income contexts where recycling markets remain underdeveloped, and communities lack incentives or infrastructure to support resource recovery [21], [22]. Overall, these results underscore that practicality and convenience strongly influence community choices. The high weight assigned to "easy to do" confirms that short-term feasibility is prioritized over long-term sustainability in Fig. 3. This contrasts with evidence from high-income countries, where policy support, recycling infrastructure, and public awareness programs have shifted community preferences towards waste separation, material recovery, and circular economy approaches [23]. These results also indicate that, despite its environmental drawbacks, burning remains the most prioritized alternative among community respondents, likely due to its convenience, independence from external infrastructure, and immediate waste volume reduction in Fig. 5. Meanwhile, Sorting, Hoarding, and Selling as well as Hoarding alone are also seen as viable and more environmentally conscious strategies, though they may require greater community involvement, awareness, and logistical support to be effectively implemented. The low ranking of the Burning and Hoarding combination suggests that the public perceives this hybrid approach as less practical or effective compared to other singular strategies.

The preference for the top-ranked waste management method can likely be attributed to its relative ease of implementation and the practical benefits it offers. This approach typically requires fewer resources, minimal infrastructure, and lower operational costs, making it an attractive option, especially in communities with limited access to advanced waste processing facilities or funding. Moreover, its simplicity allows for immediate execution without the need for extensive technical expertise or long-term planning. Despite these practical advantages, this method is associated with significant environmental drawbacks. Chief among these are the release of harmful air pollutants and the potential contamination of surrounding ecosystems, which pose serious risks to both environmental and public health in the long run [24].

In contrast, the alternatives of Sorting, Hoarding and Selling and Hoarding alone were ranked second and third, respectively. These methods reflect a growing interest in sustainable and economically beneficial waste management strategies. By promoting recycling and reuse, these approaches not only reduce the volume of waste that ends up in landfills or incinerators but also offer the potential for income generation through the sale of recyclables in Fig. 7. However, their success relies heavily on the willingness and active involvement of the local community. Moreover, they require the establishment of a more structured and coordinated waste management system, including education, logistical support, and the presence of collection and sorting, facilities factors that may not yet be fully developed in some areas.

Meanwhile, the combination of Burning and Landfilling received the lowest preference score among respondents. This result suggests that this option is perceived as the least favorable or feasible in the specific local context. From both a sustainability and practical standpoint, this approach is seen as inefficient and outdated. Burning contributes to air pollution and greenhouse gas emissions, while landfilling, particularly in unmanaged or poorly maintained sites, can lead to long-term soil and groundwater contamination. Furthermore, implementing both simultaneously may be viewed as a duplication of inefficient practices that do little to support environmental conservation or sustainable waste management goals [4], [8], [25].

From this study, several implications for sustainability household waste processing strategies elaborated. The findings suggest several key strategic focus areas that can be prioritized to enhance sustainability in the Urban household.

1. Integrated Sustainability Management: Develop a holistic sustainability strategy that balances top-ranking priorities (hygiene, market competitiveness, waste management) with lower-ranked but crucial social aspects.
2. Technology Investment: Focus on developing technologies that address multiple sustainability aspects concurrently, such as mini incinerator for household without fog.
3. Stakeholder Engagement: Need collaboration with local government, environmental agencies, and community local organizations to push wider sustainability challenges, particularly in waste management and pollution control.
4. Circular Economy Initiatives: Develop partnerships within the industry sector to create closed-loop systems, particularly in waste plastic management.
5. Innovation Hub: encouraging research partnerships with local universities and technology providers.

From a policy perspective, these findings suggest that interventions are needed to redirect waste management practices towards more sustainable alternatives. Governmental and institutional efforts should focus on:

a. Expanding recycling markets and improving economic incentives for waste separation.
b. Providing infrastructure and logistical support for material recovery.
c. Enhancing community education and awareness to highlight the environmental and health consequences of burning.

Such measures would help bridge the gap between current community practices, which are predominantly shaped by convenience, and globally recommended waste management hierarchies that emphasize reduction, reuse, and recycling. And by focusing on these strategic areas, Urban people can enhance their sustainability performance, to manage waste urban household.

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4. Conclusion

This study offers a structured evaluation of sustainable household waste treatment alternatives in Umbulharjo Sub-district, Yogyakarta, by comparing two widely used multi-criteria decision-making methods: Analytic Hierarchy Process (AHP) and Fuzzy AHP. The findings demonstrate that while AHP provides a straightforward prioritization of alternatives, it lacks the capacity to accommodate uncertainty and subjective judgments inherent in real-world sustainability challenges. In contrast, Fuzzy AHP, through the integration of linguistic variables and Triangular Fuzzy Numbers, enhances the robustness and contextual relevance of the decision-making process.

Among the evaluated alternatives, the burning method appeared dominant in the AHP analysis due to perceived ease of implementation. However, Fuzzy AHP revealed a stronger preference for the "Sorting, Hoarding, and Selling" alternative, highlighting the community's underlying support for environmentally responsible and economically viable practices. This divergence underscores the importance of incorporating fuzziness into decision support systems, particularly when evaluating socially embedded and context-specific sustainability interventions.

The methodological contribution of this study lies in its dual-layered comparison, which not only illustrates the operational strengths of Fuzzy AHP over classical AHP but also provides a replicable framework for local governments, waste management authorities, and sustainability practitioners. The approach facilitates inclusive, data-informed, and uncertainty-resilient decision-making processes, crucial for the successful deployment of cleaner production strategies in urban waste systems.

Future work may extend this analysis by incorporating other hybrid MCDM techniques (e.g., Fuzzy TOPSIS, DEMATEL) and expanding the stakeholder base to ensure broader participatory insights. Integration with lifecycle analysis and spatial decision support systems would further enhance policy relevance and contribute to more sustainable, community-aligned urban waste management solutions.

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